

Evaluation of Sustainable Asphalt Mixture

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Abstract

Waste crumb rubber has been used as one of the modified binding material for asphalt production. Three percentages of crumb rubber of 5, 10, and 15% by mass of the binder content were considered to produce crumb rubber modified bitumen "CRMB". It is proposed that different percentages of crumb rubber modified bitumen (CRMB) were mixed with the asphaltic concrete and used in paving roads. The new mix contains relatively small amount of CRMB in addition to aggregate, asphalt binder and air. Marshall Stability and flow, density, void analysis, and other characteristic tests were conducted for all these samples to evaluate the asphalt concrete road according to UAE standards. From these tests it was clearly shown that the addition of waste rubber crumb had a significant effect on the behavior of final asphalt paving road. It was found that; the more percentage added of rubber tire the higher voids in mineral aggregate; 5% rubberized bitumen yielded the maximum amount of strength among other percentages. The less the amount of rubber in the mix the higher flow can be gained; 15% of CR gave the maximum viscosity; furthermore, ductility was determined for all results. Results showed that the higher the amount of rubber crumb in the bitumen, the more chance of the sample to recover after the load is released.

Keywords

Waste Tire Powder; Bitumen; Rubber Asphalt

Introduction

Petroleum bitumen is widely used in many industries, including road building constructions. Main problem with road building is the poor quality of bitumen used in asphalt-concrete pavements. One of the ways to improve the quality of the binders is their modification with polymers and rubber crumb [Shunin D., 2002; Ongarbaev Ye, 2011]. The utilization of spent rubber materials, for example, automobile tires, is currently one of the most important environmental problems on a global scale because of the rapid growth of the automobile industry [Gorlova E. E., 2008].

Crumb rubber is a term usually applied to recycled rubber from automotive and truck scrap tires. During the recycling process steel and fluff is removed leaving tire rubber with a granular consistency. Worn or spent tires are valuable secondary raw materials containing 65–70% rubber, 15–25% technical-grade carbon, and 10–15% high-quality metal [Gorlova E. E., 2009]. Poor performance of bituminous mixtures under increased traffic volume and heavier axle load has led to the increased use and development of modified binders. Development of modified asphalt materials especially the use of discarded tires of vehicles in pavement construction is one of the steps to reduce environmental concern in many countries. Modified binders generally exhibit decreased temperature susceptibility and potentially improve mix performance [Brown S. F., 1990]. A wide interest in the use of crumb rubber modified binders in pavement construction as several laboratories and field tests reported improved overall performance of pavements [Diehl C. F., 2000]. The waste tires are powdered and the powder is blended with bitumen and aggregate [Vasudevan R., 2007]. Binders containing crumb rubber have shown improvements in durability, crack reflection, fatigue resistance, skid resistance, and mechanical characteristics over typical hot mix asphalt (HMA) mixtures [Feipeng Xiao, 2006]. Marshall's mix design was carried out by changing the modified bitumen content at constant optimum rubber content and subsequent tests have been performed to determine the different mix design characteristics. Much improved characteristics was achieved when compared with straight run bitumen and that too at reduced optimum modified binder content (5.67%) [Shankar S., 2009]. Dynamic Shear rheometer (DSR) and rheological properties of CRI1 and PMAD modified bitumen are compared with unmodified 80/100 bitumen. The advantages scrap tire include: increased fatigue life or fatigue resistance, reduced

reflective cracking and low temperature cracking, improved tensile strength, ductility, toughness, adhesion, resilience, tenacity, durability, and skid resistance [Oliver J.W.H., 2000].

The objective of this work is to conduct asphalt Marshall Design test with three different percentages of CRMB in asphalt. These percentages are 5, 10, and 15 percent of binder content. This will help to reduce the hazards that affect the environment. Moreover, the companies can reduce their production costs; hence by recycling the cost of raw materials and this will decrease the quantity of raw materials. Nowadays recycled rubber is in great demand because of its great applications.

Experimental Work

There are two processes through which rubber crumb is mixed with the Asphalt design; the wet process where the rubber crumb is mixed with hot bitumen. The mixing is continued until the interaction between crumb and bitumen is achieved. Afterwards it is mixed with the aggregates and mix as modified binder. In the dry process, the rubber crumb is mixed with the aggregate before mixing it with the bitumen. Afterwards the bitumen is modified when both of them are in contact with each other. Out of the two methods mentioned above, dry method is not preferred because of its poor results compared to the wet process.

In super Pave Design Mix, one of the most important steps, the selected aggregate should be tough enough to resist any kind of crushing and degradation from associated activities including manufacturing, stockpiling, placing, and production. Furthermore, it must be able to adequately transmit loads from the pavement surface to the underlying layers (and eventually the subgrade layer). If the aggregate lacks adequate resistance to abrasion, it will cause premature structural failure or perhaps it will lose its ability to resist skidding. To test for this property, it is commonly done using the Los Angeles Abrasion Test. we need to guarantee in our pavement mix as it provides much of the strength of the final product. The code specifies and details many tests that could be conducted on the aggregate to ensure good caliber properties that fall within the limits of these tests.

Super pave binders are classified according to PG (performances grading rating). The selection was based on expected pavement temperature. Super pave mixes are based on volumetric properties, the characteristics of the aggregate and the volumetric

properties of the mix such as air voids and voids in the mineral aggregate. Super pave system basis aggregate selection on consensus properties that apply equally at all. They include: course aggregate angularity, fine aggregate angularity, flat and elongated particles, and clay content. Course aggregate angularity is important as it doesn't lack interlock as round aggregates. The lack of interlocks makes the resultant hot mix asphalt more disposed to rutting. So basically, the use of course aggregate is to prevent rut.

Each stockpile coarse aggregate shall have properties as shown in Table 1. Mineral aggregate properties for asphaltic concrete mixes are shown in Table 2.

TABLE 1: COARSE AGGREGATE PROPERTIES

Los Angeles Abrasion Loss (ASTM C-131 or C-535) Base course and binder course Wearing course	30% Max 25%Max
Aggregate crushing value (BS 812: part 110) Base course and binder course Wearing course	25% Max 20%Max
Soundness Loss (ASTM C88) 5 cycles Magnesium Sulphate	10% Max
Acid soluble chlorides (BS 812: Part 117)	0.1%Max
Acid soluble Sulphates (BS EN 1744-1(1998))	0.5%Max
Flakiness Index (Bs 812: Part 105.1) Base course and binder course Wearing course	30% Max 25%Max
Water Absorption (ASTM C127)	2.0%max
Limit for organic matter content shall be max when tested as per BS 1377: P3:1990:M3	2.0%

Super pave, which stands for superior performing asphalt pavements, is one of the recent methods needed to construct and design asphalt pavements that can perform better and last longer under wide range of traffic loads and extremes of temperature. This method is actually designed to replace the Hveem and Marshall methods. Moreover, it allows us to design more durable asphalt pavement. This system contains asphalt binder and aggregate in its mix design. "it assess binder and mix performances in terms of the most common causes of pavement failure: pavement deformation (rutting), fatigue (structural) cracking, and low-temperature (thermal) cracking." [Frye, 2002].

Super Pave Design Mix consists of 3 main steps

- Selecting the aggregates, binders, and modifiers to be used in the mix
- Select the design aggregate structures
- Select the design asphalt binder content

The Super pave binders are classified by PG, for performances grading rating. They are selected based on

TABLE 2: SUMMARY OF MINERAL AGGREGATE TEST PROPERTIES FOR ASPHALTIC CONCRETE MIXES

S.NO.	Property	Test method	Aggregate Size			Specification Limits	Remark
			10-20 mm	5-10 mm	0-5 mm		
1	Flakiness Index	BS 812:part105 S105.1	11	16	-	25 Max	Complies
2	Elongation Index	BS 812:part105 S105.2	22	23	-	25 Max	Complies
3	Loss by Abrasion Test	ASTM C131/C535	8	11	-	25 Max	Complies
4	Agg.Crushing Value	BS 812:1990 P 110	-	-	-	20 Max	Complies
5	Soundness Loss (Magnesium Sulphate)	ASTM C 88: 05	-	-	-	10 Max	Complies
6	Acid Soluble Chlorides	BS 812: 1988 P117	Nil	Nil	Nil	0.1 Max	Complies
7	Acid Soluble Sulphates	BS EN 1744-2:1998	0.02	0.03	0.03	0.5 Max	Complies
8	Liquid Limit / Plastic Limit	BS 1377 Part2:1990 T4.5, T5.3	-	-	NP	25 Max	Complies
9	Plasticity Index	BS 1377:Part 2	-	-	NP	NP	Complies
10	Water Absorption	ASTM C 127/C128	0.4	0.6	0.8	2 Max	Complies
11	Fully Crushed faces analysis	DMS – 7:2001(R07)	95	-	-	85 Max	Complies
12	One Face Crushed faces analysis	DMS – 8:2001(R07)	100	100	-	100 Max	Complies`

the expected pavement temperature. The rating contains 2 numbers, high and low pavement temperature. For example, a PG of 58-16 is expected to have a rut resistant to 64 C and crack resistant to 16 C. furthermore, to select pavement binder; we need to determine the average of 7 day maximum pavement design temperatures, and minimum pavement temperature. Super pave mixes are based on volumetric properties, the characteristics of the aggregate and the volumetric properties of the mix such as air voids and voids in the mineral aggregate. Super pave system basis aggregate selection on consensus properties that apply equally at all location, they include:

- Course aggregate angularity
- Fine aggregate angularity
- Flat and elongated particles
- Clay content

Course aggregate angularity is important as it doesn't lack interlock as round aggregates. The lack of interlocks makes the resultant hot mix asphalt more disposed to rutting. So basically, the use of course aggregate is to prevent rut as shown in Table 3. This table shows course aggregate angularity requirements (AASHTO).

TABLE 3: COURSE AGGREGATE ANGULARITY REQUIREMENTS (AASHTO)

20-yr Traffic loading (in millions of ESALs)	Depth from Surface	
	≤ 100 mm (4 inches)	> 100 mm (4 inches)
< 0.3	55/-	-/-
0.3 to < 3	75/-	50/-
3 to < 10	85/80	60/-
10 to < 30	95/90	80/75
≥ 30	100/100	100/100

The same goes to fine aggregate angularity; it's

important because having a rounded fine aggregate could lead to HMA rutting. The more voids, the more angular the aggregate as shown in Table 4.

TABLE 4: FINE AGGREGATE ANGULARITY REQUIREMENTS (AASHTO)

20-yr Traffic Loading(in millions of ESALs)	Depth from Surface ≤ 100 mm (4 inches)	> 100 mm (4inches)
< 0.3		
0.3 to < 3 3 to < 10	40	40
10 to < 30 ≥ 30	45	45

Numbers shown represent the minimum uncompacted void content as a percentage of the total sample volume.

Flat and Elongated Particles could be harmful for the HMA, it will be breakdown during compaction and it will decrease the workability of the mix. To investigate the amount of clay content, the following table is required.

TABLE 5: SAND EQUIVALENT TEST REQUIREMENT

20-yr Traffic Loading (in millions of ESALs)	Minimum Sand Equivalent (%)
< 0.3	40
0.3 to < 3	
3 to < 10	45
10 to < 30	
≥ 30	50

Several trials of aggregate-asphalt binder were performed and the optimum asphalt binder was chosen. The trial blends must contain a range of asphalt contents above and below the optimum asphalt content in order to work. So basically, the first step was to estimate optimum asphalt content.

The CRMB was mixed with the aggregates in order to be tested for the Marshall design. Three different percentages of CRMB in bitumen were used such as

5%, 10% and 15%. Furthermore samples with different percentages of bitumen in the whole sample such as 3% bitumen to 6% bitumen with intervals of 0.5%. The following tests were conducted to reflect the most important tests to see the effects of the crumb rubber on asphalt mix. These tests are; Marshall Stability and flow, and density and void analysis. The Procedure to determine Marshall Stability of bituminous mixture is as follow: heat the weighed aggregates and the bitumen separately up to 170°C and 163°C respectively. Mix them thoroughly, transfer the mixed material to the compaction mould arranged on the compaction pedestal. Give 50 blows on the top side of the specimen mix with a standard hammer (45cm, 4.86kg). Reverse the specimen and give 50 blows again. Take the mould with the specimen and cool it for a few minutes. Remove the specimen from the mould by gentle pushing. Mark the specimen and cure it at room temperature, overnight. Series of specimens are prepared by a similar method with varying quantities of bitumen content, with an increment of 0.5% (3 specimens) or one bitumen content. The temperature of the mould was kept in water bath at 60°C for half an hour. The stability of the mould was checked on the Marshall Stability apparatus.

Results and Discussion

Void in Total Mix is a property refers to the total amount of voids that are present in the mixture after preparing the sample. Voids are the spaces in the samples that are left even after the compaction has been done. The voids that present in the total mix are shown in Figure 1. The 5% crumb bitumen, as the percentage in total mix is increased the void in the total mix decreases. For example if the values of 3.5% to 6% were compared, the later has more voids in it compared to 3.5%. Similar trends can be seen for 10% and 15% when taking different percentages of it in the mix.

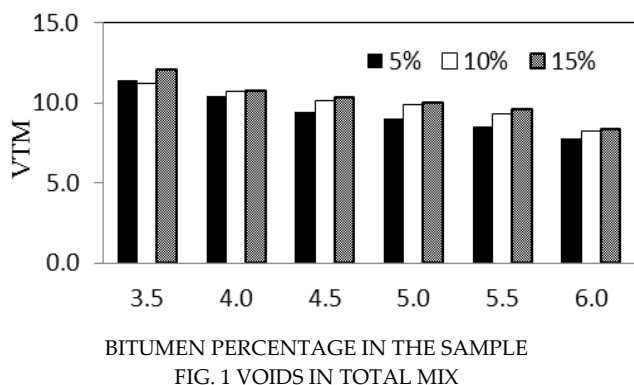


FIG. 1 VOIDS IN TOTAL MIX

Voids in Mineral Aggregate are defined as the portion of the space in a compacted specimen which is not

occupied by the aggregate. When a high air void content is available, it could allow for the intrusion of water into the mix. In our study the more we added certain percentages of rubberized bitumen in it, the higher we got the voids in mineral aggregate. The next property is about the voids that are present in the aggregate that are being used. Upon drawing the bar chart it shows that as the percentage of the bitumen is increased the voids in the aggregate get increased. Looking into the trend of the 10% rubberized bitumen, from using it 3>5% to 6% the voids in the aggregate mix keeps on increasing. Similar trends can be seen for 5 and 15% mix. An interesting result can be seen at the 6% o each mix because it gives exactly the same amount of the voids in the mixture.

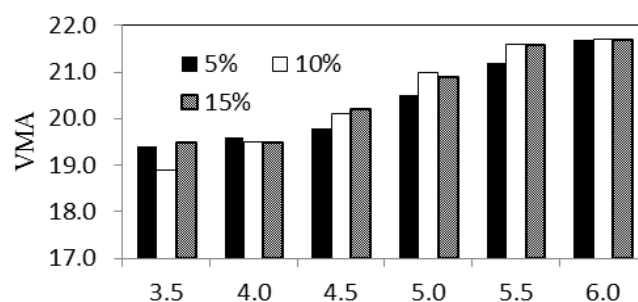


FIG. 2 VOIDS IN MINERAL AGGREGATE

Voids Filled with Bitumen is the ratio of the voids in the mineral aggregate frame work filled with the bitumen. While mixing higher percentages of bitumen in the sample, the voids kept on increasing.

Similar trends were seen for 10% and 15% mix showing us a direct relation. This property is related to the voids that are filled in the bitumen itself. The more we add the percentage of the bitumen, the more percentage of voids is present in it showing a direct relationship. It can be seen that an optimum percentage of the bitumen should be used in order to get certain percentage of void that will not affect the performance of the mix. The 5% rubberized bitumen gives the maximum amount of the voids in the bitumen.

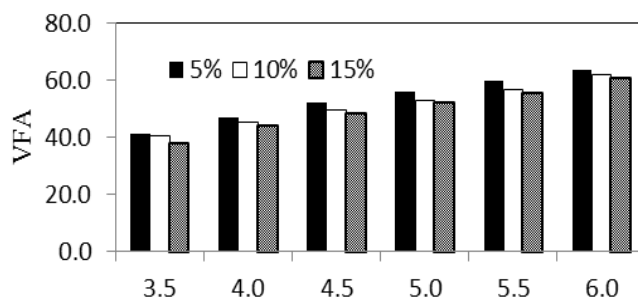
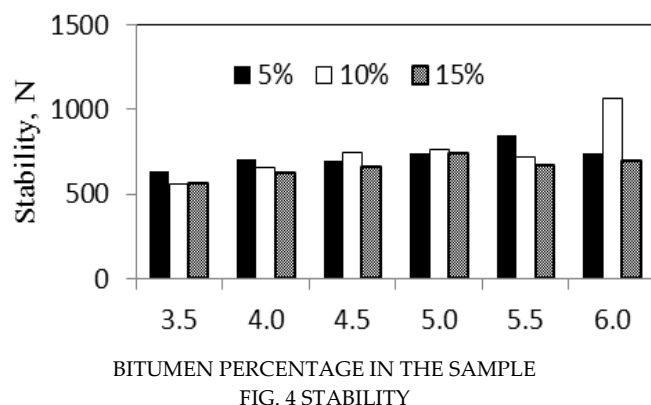


FIG. 3 VOIDS FILLED WITH MITUMEN

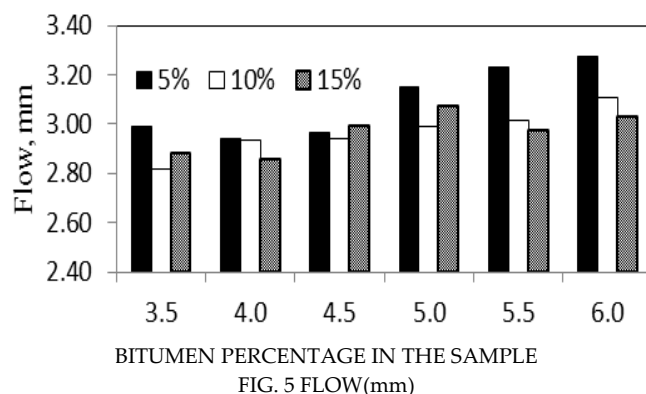
Stability represents the maximum amount of the load that the specimen can bear. It is a parameter for strength. In our case the 5% rubberized bitumen gave us the maximum amount of strength out of all. As its percentage is increased in the mix, the strength kept on increasing for all cases. Although 10% bitumen when used in 6% in the whole mix gave us the highest strength of all but that won't be cost effective. Stability is one of the key properties in the materials. This trend is not linear compare to what we have seen before. For 5% rubberized bitumen it increases first, decreases and then finally increases again. Similar trends are also seen for 10% and 15% rubberized bitumen. The optimal percentage would be around 4.5%. Another factor that should be kept in the mind is that although at 6% it gives the maximum stability but it would be really costly. Keeping this thing in mind an optimal percentage should be used considering cost and performance.



Flow is the vertical deformation of the specimen which represents how the actual mix will behave when implemented with respect to plastic flow. Our results weren't linear in terms of the flow. For example for 5% rubberized bitumen it gave us highest value of flow but then decreased. After a while for higher percentages flow was maximum for 5% rubberized asphalt. This shows that the less the amount of rubber in the mix, the higher will be the flow. Lastly the property of the flow is compared between different rubberized bitumen content. The best result is given by using 5% rubberized bitumen. It decreases initially but later on keeps on going high. On the hand 10% and 15% crumb doesn't follow a linear path; it initially increases then decreases and final increases. Keeping in view this trend it is ideal to use 5% crumb to get maximum stability around 4.5 %.

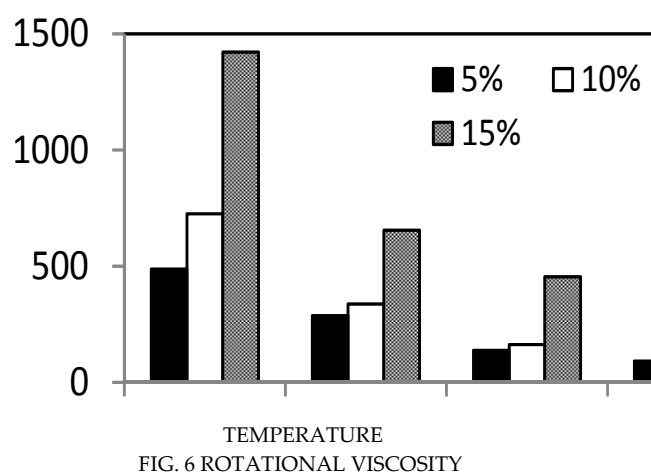
Rotational viscosity is a property of a fluid which determines the rate at which local angular momentum differences are equilibrated. In our result initially, 15%

gave the maximum viscosity of the three mixes. But as the temperature was increased the viscosity kept on decreasing showing inverse relation.



Three bitumen mixtures were prepared having crumbs of 5%, 10% and 15% in it. They were represented as BP1261A, BP162A and BP163A. Different properties of it are compared in following paragraphs.

As the temperature is increased, the rotational viscosity keeps on decreasing with the increase of bitumen. The more the rubberized bitumen, the higher is the rotational viscosity. The temperature of the mould was kept in water bath at 60°C for half an hour. The stability of the mould was checked on the Marshall Stability apparatus. Three bitumen mixtures were prepared having crumbs of 5%, 10% and 15% in it. They were represented as BP1261A, BP162A and BP163A.



Penetration is a property refers to the ductility and stiffness of the sample. This test was performed at 25 °. The bar charts shows that the less the amount of the rubberized bitumen, the higher will be the penetration; although the difference between the 5% and 10% isn't that much while 15% was way off from the normal.

Ductility can be defined as the ability of the solid

materials to deform under tensile stress. It is mostly characterized by the material's ability to be stretched into a wire. It is shown that the lower rubberized crumb in the bitumen, the highest the ductility is achieved. When moving from 5% to 10%-15% it gave almost similar result. Ductility is increased if the rubber crumb is least among all. The ductility for 10 and 15% is almost the same.

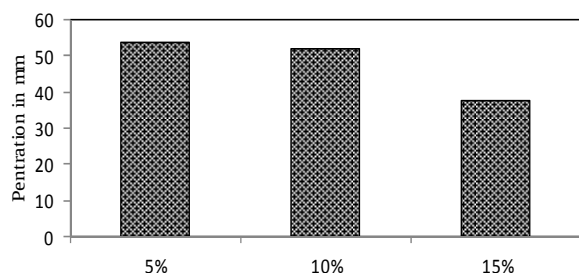
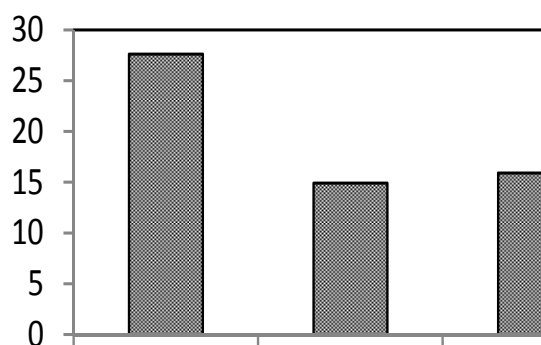
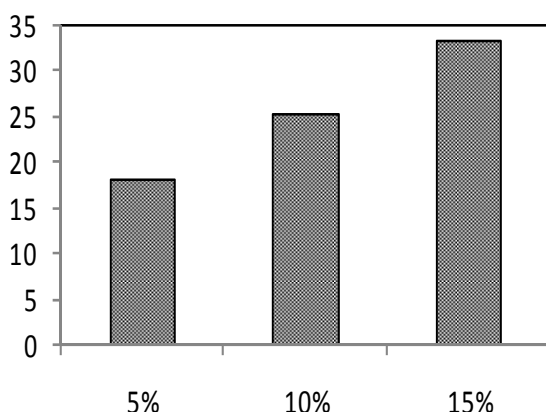


FIG. 7 PENETRATION AT 25°C WITH DIFFERENT PERCENTAGE OF RUBBER



RUBBER PERCENTAGE
FIG. 8 DUCTILITY



RUBBER TIRE PERCENTAGE
FIG. 8 ELASTIC RECOVERY

When the load is released during the stress-strain test, some of the total deformation is recovered known as elastic deformation. The three comparisons of the mix show that the higher the rubber crumb in the bitumen, the more chance that the sample is recovered after the load is released. Elastic recovery is increases as the

percentage of the rubberized crumb is increased. The elastic recovery is highest for 15% and lowest for 5% rubberized crumb.

The main problem with mixing of the crumb in Asphalt for both processes is the lack of cohesion between the crumb and bitumen. If the interaction between the crumb and bitumen is weak, this will cause the lower resistance to moisture hence reducing the bearing capacity of the pavement. The main disadvantage of mixing of crumb with the Asphalt is the instability part. The properties which effects the instability are crumb rubber size, percentage of the crumb rubber used, degree of penetration and softening point of the bitumen. The higher the number of variables, the higher is the variation of the results. As far the water content is concerned, because of low Specific gravity and high area of the rubber crumb the water requirement was higher than usual.

Conclusion

Waste crumb rubber had been used as one of the modified binding material for asphalt production. Three percentages of crumb rubber 5, 10, and 15% by mass of the binder content were considered to produce crumb rubber modified bitumen "CRMB". It was shown that the addition of 5% is adequate to satisfy UAE standards. When the temperature is increased, the rotational viscosity keeps on decreasing with the increase of bitumen. It is also shown that the more the rubberized bitumen, the higher is the rotational viscosity. Waste rubber tire was used as environmental friendly and sustainable material. It would be also beneficial for the longer run to reduce the cost of the raw materials that are used in the construction of the roads.

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